Diversity of grasslands in the Biele Karpaty Mts. (Slovak Republic)

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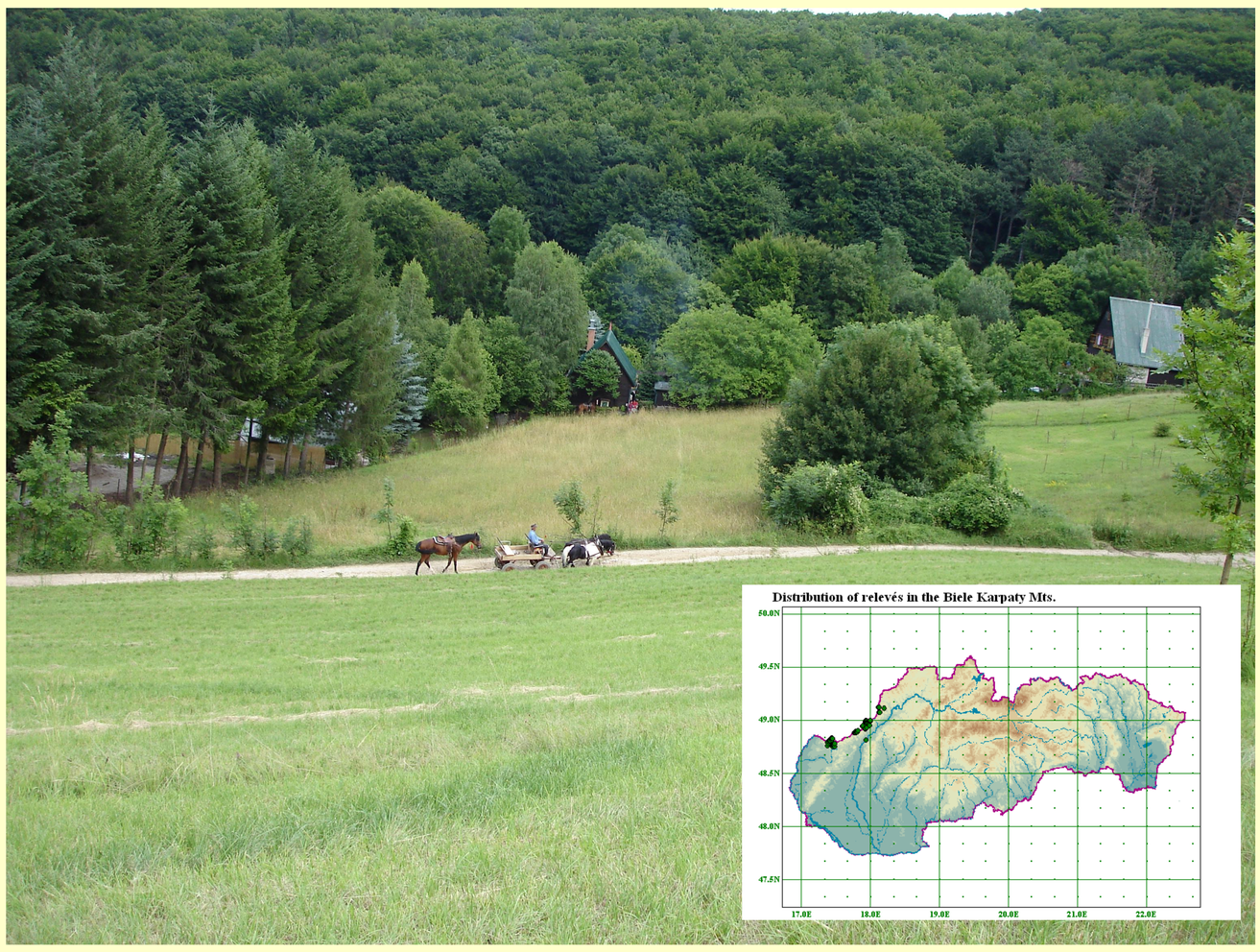


Introduction
The Biele Karpaty Mts. lie in Central Europe, along the border between Slovakia and the Czech Republic. Meso- and subxerophyllous grasslands of the Biele Karpaty Mts. are famous for their great species richness: sometimes, up to 80 species of vascular plants may occur in a plot of just 25 m2. Such incredible species diversity is a result of the long-term care of grasslands (regular mowing and grazing) and rather variable environmental conditions. Species richness is generally determined by various factors (Palmer 1994). In our research, we have focused on several environmental variables with the aim to find a degree they are responsible for species composition in studied plant communities.

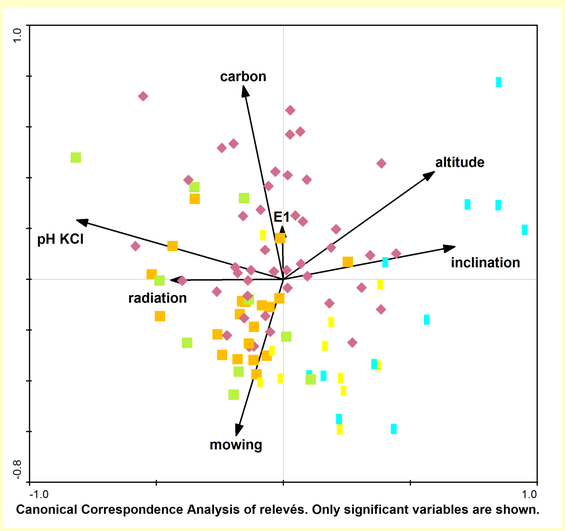
Aims
to investigate the effect of environmental factors on species composition of grasslands
to evaluate the relationship between environmental factors and species diversity parameters (α-diversity, Shannon-Wiener's index of diversity, equitability)

Methods
Factors that affect species composition and diversity of grasslands were studied in a set of 98 phytosociological relevés. Soil parameters (pH, the content of CaCO3, nitrogen, carbon and humus), topographical factors (exposition, inclination, altitude, radiation) and biological variables (cover of both herb and moss layers, litter cover), as well as the management (grazing, mowing, abandonment), were determined and recorded for each relevé.
Extremely different relevés were excluded with the outlier analysis using the PC-ORD 4 program (McCune & Mefford 1999) and the Sörensen's index. The remaining data set contained 96 relevés with 289 species.
The classification was performed over the cluster analysis (PC-ORD 4) using the relative Euclidean distance as a distance measure and the Ward's group linkage method. Diagnostic species for the clusters were determined over the calculation of fidelity of each species to each cluster, using the phi coefficient of the association (Chytrý et al. 2002) in the program JUICE 6.3.49 (Tichý 2002). The relationship between species composition and defined environmental factors was analysed over the canonical correspondence analysis (CCA) using the CANOCO 4.5 package (ter Braak & Šmilauer 2002). All studied environmental factors were tested by the Monte Carlo permutation test with unrestricted permutations (999 permutations, P = 0.05). Finally, the pure effect (where the percentage variance is explained by the variable while the remaining significant variables were used as co-variables) was calculated. Pure variance is expressed as % of total inertia.
The relationship between studied environmental factors and species diversity parameters (α-diversity, Shannon-Wiener's index of diversity, equitability) was evaluated through the correlation analysis using the Pearsson's correlation coefficient.

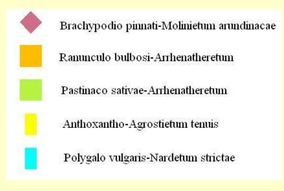
Results and discussion
The numerical classification distinguished 5 associations:
Festuco-Brometea
***Bromion erecti* W. Koch 1926**
Brachypodio pinnati-Molinietum arundinacae Klika 1939
Molinio-Arrhenatheretea
***Arrhenatherion* Koch 1926**
Ranunculo bulbosi-Arrhenatheretum Ellmauer 1993
Pastinaco sativae- Arrhenatheretum elatioris Passarge 1964
***Cynosurion* R. Tx 1947**
Anthoxantho-Agrostietum tenius Sillinger 1933 subas. *typicum*
Anthoxantho-Agrostietum tenius Sillinger 1933 subas. *nardetosum*
Nardetea strictae
***Violion caninae* Schwickerath 1944**
Polygalo-Nardetum (Preising 1933) Oberd 1957

Environmental variables used in the Canonical Correspondence Analysis:
pH KCl - soil acidity in KCl
carbon - organic carbon content (%/100 g organic matter)
nitrogen - total nitrogen (%/100 g organic matter)
CaCO3 - content of calc-spar (%/100 g organic matter)
humus - content of humus (%/100 g organic matter)
mowing - three values 1 – non-mowed, 2 - irregularly mowed, 3 - regularly mowed
grazing - 1 - grazed, 0 – non-grazed
litter - 1 - presence of dead plant biomass, 0 - absence of dead plant biomass
radiation - the annual direct radiation by McCune and Keon (2002) estimated over the slope, aspect and latitude
inclination - slope inclination (°)
altitude - m a.s.l
E1 - cover of herb layer (%)
E0 - cover of moss layer (%)

As the humus and carbon correlate strongly positively, the humus was excluded from the CCA analysis. The first CCA axis produced 3.7 % variance of the species data and 25.6 % of the species–environment relationship, whereas the second axis produced 3.2 % variance of the species data and 22.6 % of the species–environment relationship. The significance of all canonical axes was tested (Trace: 0.542, P=0.0001) upon the inclusion of the seven environmental variables, which were passed by the forward selection as significant.
All environmental factors explained 0.76 % of the whole variability of samples. pH KCl, carbon content, mowing, altitude, E1, radiation and inclination factors proved to be significant in the Monte Carlo permutation test explaining 0,54 % of the whole variability. pH KCl, E1, altitude and radiation had a significant pure effect on species composition of grasslands.



Canonical Correspondence Analysis of relevés. Only significant variables are shown.



Canonical correspondence analysis					
Axes	1	2	3	4	Total inertia
Eigenvalues :	0.139	0.123	0.07	0.067	3.785
Species-environment correlations :	0.864	0.851	0.832	0.836	
Cumulative percentage variance					
of species data :	3.7	6.9	8.8	10.5	
of species-environment relation:	25.6	48.2	61.2	73.4	
Sum of all eigenvalues					3.785
Sum of all canonical eigenvalues					0.542

Environmental variable	Conditional effect (selection order)	%	Marginal effect	%	Pure effect	%
pH KCl	**0.114**	**15.0**	**0.114**	**15.0**	**0.065**	**8.5**
Carbon	**0.093**	**12,2**	**0.098**	**12.8**	0.037	4.8
Mowing	**0.083**	**10.9**	**0.087**	**11.4**	0.045	5.9
Altitude	**0.074**	**9.7**	**0.099**	**13.0**	**0.057**	**7.5**
E1	**0.064**	**8.4**	**0.064**	**8.4**	**0.057**	**7.5**
Radiation	**0.057**	**7.5**	**0.068**	**8.9**	**0.052**	**6.8**
Inclination	**0.057**	**7.5**	**0.091**	**11.9**	0.045	5.9

Conditional effect - additional variance explaned by the variable at the time it was included in the forward selectin. **Marginal effect** - variance explaned by the variable while used as the only constraining variable. **Pure effect** - variance explaned by the variable after all other significant variables were used as covariables

The correlation between the species diversity parameters and environmental factors has shown, that at the level of probability P = 0.05 the number of species weakly positively correlate with the content of nitrogen, carbon, humus and the altitude. The Shannon-Wiener's index positively correlated with the content of carbon, humus, radiation and the equitability with radiation. Weak correlations confirm the synergetic effect of many factors on species diversity. Generally, intermediate values of environmental factors are more favourable for the diversity than low or high values. This corresponds with the „resource balance hypothesis of plant species diversity", which says that the plant species diversity is favoured when actual resource supply rations are balanced according to the optimum resource supply rations for the vegetation as a whole (Braakhekke et al. 1999).

Correlations between parameters of species diversity and environmental factors
Marked correlations are significant at p < .05000

	pH_KCl	CaCO3	Nitrogen	Carbon	Humus	Inclination	E1	E0	Litter	Altitude	Radiation	Mowing	Grazing
Number of species	-0.08	-0.06	**0.22**	**0.35**	**0.34**	0.07	**0.21**	-0.04	-0.04	**0.32**	0.15	0.08	0.17
Shannon-Wiener index	0.02	0.03	0.08	**0.23**	**0.23**	0.00	0.17	0.04	-0.11	0.13	**0.20**	0.15	0.02
Equitability	0.10	0.09	-0.02	0.11	0.12	-0.08	0.10	0.11	-0.17	-0.05	**0.23**	0.20	-0.10

In the Biele Karpaty Mts., the grasslands of the *Brachypodio-Molinietum arundinacae* have the highest α-diversity in comparison with the other studied plant communities. The number of vascular species was examined in various sizes of plots of this community with the occurrence of 22 species in the plot of 0.04 m2, 55 species in the plot of 1 m2, and 81 species in the plot of 9 m2.

Number of observed species in the plots of various sizes of the *Brachypodio-Molinietum arundinacae*											
Plot size m^2	0,04	0,08	0,16	0,32	0,64	1	2	3	4	9	25
Average number of species	18	24	31	38	45	48	54	54	56	81	72
Number of measurements	225	100	40	20	10	9	4	2	2	3	7
Mode	20	22	33	36	44	47	54	-	-	-	-
Median	18	24	31,5	37	44	48	54	-	-	-	70
Minimum	10	16	24	31	40	43	51	51	55	80	64
Maximum	22	33	40	51	53	55	57	57	57	82	81

Average values of species diversity parameters			
Plant community	Number of species	Shannon-Wiener index	Equitability
Brachypodio pinnati-Molinietum arundinaceae	61	3.62	0.89
Ranunculo bulbosi-Arrhenatheretum	56	3.45	0.91
Pastinaco sativae- Arrhenatheretum elatioris	48	3.63	0.84
Anthoxantho-Agrostietum tenius	55	3.60	0.90
Polygalo-Nardetum	49	3.27	0.84

Synoptic table with modified fidelity phi coefficient and percentage

Group No.	1	2	3	4	5
No. of relevés	42	20	10	11	13
Cirsium pannonicum	62.8 81	--- 15	--- .	--- 18	--- 15
Lathyrus latifolius	59.7 69	--- 10	--- .	--- 9	--- 15
Chamaecytisus supinus	54.4 52	--- 10	--- .	--- 9	--- .
Brachypodium pinnatum	53.5 98	--- 25	--- 40	--- 36	--- 23
Betonica officinalis	49.9 74	18.1 45	--- .	--- 9	--- 15
Filipendula vulgaris	45.1 98	--- 50	--- 30	2.0 55	--- 31
Peucedanum cervaria	39.8 19	--- .	--- .	--- .	--- .
Melampyrum cristatum	39.8 19	--- .	--- .	--- .	--- .
Galium verum agg.	39.2 79	10.0 50	--- 40	--- 9	--- 23
Carex montana	38.9 81	--- 20	--- 20	3.0 45	3.7 46
Polygala major	37.1 17	--- .	--- .	--- .	--- .
Thesium linophyllon	36.6 26	5.3 10	--- .	--- .	--- .
Lathyrus niger	34.3 14	--- .	--- .	--- .	--- .
Trifolium montanum	33.4 83	25.1 75	--- 10	--- 27	4.0 54
Centaurea scabiosa	33.3 19	--- 5	--- .	--- .	--- .
Ononis spinosa	32.1 48	22.8 40	--- 10	--- 9	--- .
Primula veris	31.9 90	26.3 85	11.0 70	--- 27	--- 23
Viola hirta	31.6 74	12.6 55	--- 40	--- 36	--- 8
Salvia pratensis	31.2 88	23.0 80	2.8 60	--- 27	--- 31
Aquilegia vulgaris	30.4 19	--- .	--- .	--- .	5.2 8
Tanacetum corymbosum	30.4 19	--- .	--- .	--- .	5.2 8
Genista tinctoria	30.2 29	7.8 15	--- .	--- .	--- 8
Trifolium rubens	30.0 33	--- .	--- .	--- 9	14.8 23
Inula salicina	29.3 26	1.3 10	1.3 10	--- .	--- .
Polygala comosa	--- 14	**58.1 65**	--- .	--- 9	--- 8
Ornithogalum umbellatum s.lat	--- 2	**42.9 25**	--- .	--- .	--- .
Trifolium ochroleucon	--- .	**42.5 30**	--- .	--- .	--- 8
Onobrychis viciifolia	--- 12	**41.9 40**	--- 10	--- .	--- .
Bromus erectus	26.9 81	**41.0 95**	5.8 60	--- 27	--- 8
Plantago media	--- 55	**39.6 95**	4.4 60	--- 45	--- 23
Daucus carota	--- 17	**37.4 75**	--- 30	25.7 64	--- 8
Linum catharticum	3.1 43	**35.9 75**	--- 10	24.3 64	--- 8
Festuca rupicola	12.3 52	**35.4 75**	--- 30	--- 36	--- 8
Medicago falcata	20.1 48	**33.7 60**	--- 30	--- 9	--- .
Prunella vulgaris	--- 55	**29.7 85**	--- 20	8.2 64	--- 54
Ranunculus bulbosus	--- 2	**28.8 40**	2.7 20	12.2 27	--- .
Lathyrus tuberosus	--- .	**28.6 10**	--- .	--- .	--- .
Glechoma hederacea s.lat.	--- .	--- 10	**60.5 60**	--- 9	--- .
Asarum europaeum	--- .	--- .	**50.5 30**	--- .	--- .
Myosotis arvensis	--- 5	--- .	**45.3 30**	--- .	--- .
Campanula rapunculoides	--- 2	--- 10	**42.2 40**	--- 9	--- .
Taraxacum sect. Ruderalia	1.1 50	--- 45	**41.1 90**	--- 36	--- 23
Poa pratensis s.lat.	--- .	--- .	**40.8 20**	--- .	--- .
Geum urbanum	--- .	--- .	**40.8 20**	--- .	--- .
Fragaria moschata	--- .	--- .	**40.8 20**	--- .	--- .
Crepis biennis	--- 31	17.1 50	**38.2 70**	--- 18	--- .
Securigera varia	--- 5	7.8 20	**36.2 40**	--- .	--- 8
Clinopodium vulgare	--- 5	--- .	**34.7 20**	--- .	--- .
Galium mollugo agg.	--- 2	26.0 45	**31.9 50**	--- 18	--- .
Bromus hordeaceus	--- .	--- .	**31.6 20**	--- .	4.7 8
Medicago lupulina	--- 5	14.5 20	**30.5 30**	--- .	--- .
Carex sylvatica	--- .	22.4 25	**30.4 30**	--- .	--- .
Aegopodium podagraria	--- .	--- .	**30.3 20**	7.0 9	--- .
Poa pratensis	13.0 36	--- 20	**29.6 50**	--- 9	--- 8
Arrhenatherum elatius	5.1 79	18.1 90	**29.51**	--- 64	--- 38
Viola reichenbachiana	--- .	8.4 10	**29.5 20**	--- .	--- .
Bellis perennis	--- .	8.4 10	**29.5 20**	--- .	--- .
Cirsium acaule	--- .	--- .	**28.6 10**	--- .	--- .
Myosotis sylvatica agg.	--- .	--- .	**28.6 10**	--- .	--- .
Vincetoxicum hirundinaria	--- .	--- .	**28.6 10**	--- .	--- .
Geranium palustre	--- .	--- .	**28.6 10**	--- .	--- .
Urtica dioica	--- .	--- .	**28.6 10**	--- .	--- .
Hieracium pilosella	--- 7	--- .	--- 10	**57.4 55**	--- .
Euphrasia rostkoviana	--- 7	--- 20	--- 10	**43.4 55**	--- 8
Danthonia decumbens	7.7 40	--- 10	--- 20	**41.9 73**	--- 23
Hypochaeris radicata	--- 2	--- .	--- .	**41.1 36**	7.3 15
Thymus pulegioides	--- 40	--- 40	--- 30	**39.1 82**	--- 23
Origanum vulgare	--- .	--- .	--- .	**38.9 18**	--- .
Holcus lanatus	--- 31	--- 25	15.9 60	**37.9 82**	--- 23
Festuca ovina	--- 2	--- .	--- .	**35.4 18**	--- .
Agrostis capillaris	10.3 81	--- 55	--- 30	**31.41**	22.9 92
Sanguisorba minor	--- 19	8.7 35	--- 20	**30.6 55**	--- 8
Cruciata glabra	6.1 79	--- 35	--- 60	**30.31**	21.6 92
Viola canina	9.6 52	--- 20	--- .	**30.2 73**	26.6 69
Crepis praemorsa	4.7 7	--- .	--- .	**29.9 18**	--- .
Trifolium campestre	--- 2	--- 5	--- .	**29.7 18**	--- .
Carex panicea	4.7 19	--- 15	--- .	**28.6 36**	--- 8
Cynosurus cristatus	--- 31	10.2 55	5.2 50	**28.1 73**	--- 15
Luzula luzuloides	--- 2	--- .	--- .	--- .	**73.0 62**
Hypericum maculatum	--- 26	--- 5	--- 20	--- 27	**67.11**
Hieracium murorum	--- .	--- .	--- .	--- .	**51.2 31**
Phyteuma spicatum	--- 5	--- .	--- 10	--- 9	**46.3 46**
Nardus stricta	--- 5	--- .	--- 10	24.6 45	**43.3 62**
Laserpitium latifolium	--- 2	--- .	--- .	--- .	**40.9 23**
Hypochaeris maculata	26.0 50	--- 5	--- .	--- 18	**39.0 62**
Tussilago farfara	--- 5	--- .	--- .	--- .	**38.2 23**
Primula elatior	--- .	--- .	--- .	--- .	**35.6 15**
Carlina acaulis	9.8 57	--- 10	--- 20	25.4 73	**29.6 77**
Campanula glomerata	45.1 93	32.2 80	--- 20	--- .	--- **46**
Polygala vulgaris	--- 19	--- 5	--- 10	**51.5 91**	**37.2 77**
Stellaria graminea	--- 36	--- 25	--- 30	**30.4 82**	**33.2 85**
Potentilla erecta	3.0 55	--- .	--- 30	**30.1 82**	**40.6 92**
Koeleria pyramidata agg.	6.3 29	--- 5	--- .	15.6 36	**27.2 46**
Campanula persicifolia	13.4 29	--- 5	--- 10	--- 9	**26.2 38**
Alchemilla vulgaris s.lat.	--- 50	--- 40	1.5 70	24.0 91	**25.5 92**
Rumex acetosa	--- 74	--- 70	20.91	--- 82	**20.91**

Conclusion
The results of the CCA analysis demonstrated that out of 12 environmental variables the most strong effect on the data set variability was predominantly produced by pH KCl, E1, altitude and radiation. The parameters of species diversity correlated with the content of nutrients, altitude and radiation only weakly.

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